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Title:

ELASTIC PRECURSOR DECAY IN HMX EXPLOSIVE CRYSTALS

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ELASTIC PRECURSOR DECAY IN HMX EXPLOSIVE CRYSTALS *

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Abstract. VISAR experiments were performed on beta-phase HMX (cyclotetramethylene tetranitramine) crystals to measure the elastic precursor decay as a function of crystal orientation. Strong precursor decay in the first three mm of propagation was observed. There was significant dependence on impact stress, but the decay was about the same for both orientations.

INTRODUCTION

The first studies of elastic precursor decay in explosive crystals were performed by P. M. Halleck and Jerry Wackerle in pentaerythritol tetranitrate (PETN).(1) A dramatic dependence of precursor strength on crystal orientation was noted in PETN in work at Los Alamos.(2) Additional studies on PETN were performed at Institute St. Louis.(3–5) In the case of PETN the orientations with large elastic precursors also were more sensitive to shock initiation. In work reported here we present results of VISAR experiments performed on two orientations of HMX crystal to observe the nature of elastic precursor decay as a function of crystal orientation in this monoclinic explosive crystal.

EXPERIMENTAL TECHNIQUE

Plane shock experiments were performed on HMX crystals with final shock states of about 1.4 and 2.4 GPa obtained using a light-gas gun facility. Particle velocity vs time histories were recorded at the HMX/window interface using a velocity interferometer. Projectiles made of 2024 aluminum were impacted on x-cut quartz or Kel-F anvil disks. The HMX crystals were mounted on the aluminum-coated, anvil disc with a silicone elastomer.

The crystal slabs were cut from larger crystals using a low-speed, diamond saw. Identification of crystal planes was achieved by comparison of interfacet angles measured with a protractor with calculated angles until unique agreement was obtained. Lateral dimensions of the slabs were 8 to 11 mm. The crystals were polished using a series of polishing sheets consisting of alumina embedded in plastic. The crystals were water-clear and inspected with a binocular microscope at magnifications up to 50x to make sure that the interiors were free of inclusions and other visible defects larger than about 2 microns. Crystals were grown by Howard Cady by slow evaporation from acetone solution.

For VISAR studies polymethylmethacrylate (PMMA, Mil. Spec. P-5425D, preshrunk) windows 12.7 mm in both diameter and thickness were bonded to the window with elastomer. The surface of the PMMA adjacent to the crystal was coated with a diffuse aluminum mirror for VISAR particle velocity measurements. The lateral sides of the crystal and window were surrounded by an impedance-matching mixture of epoxy and 40

*Work performed under the auspices of the U. S. Department of Energy and partially supported by the Department of Defense/Office of Munitions under the Joint DoD/DOE Munitions Technology Program and the Explosives Technology Program at LANL.

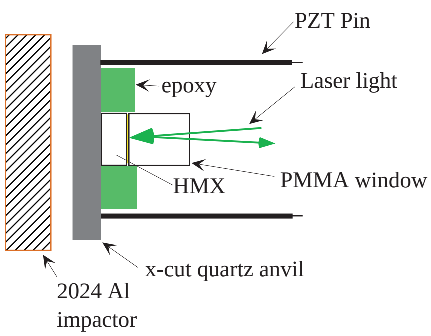

FIGURE 1. Schema of the gun impact experiment with VISAR (velocity interferometry system for any reflector) instrumentation. There is a mirror on the window at the interface.

vol% silica to keep out edge effects.

Two or four piezoelectric pins were placed on the rear surface of the anvil disc adjacent to the crystal. See Fig. 1. The average impact time for a pair of diametrically placed pins is a measure of impact time in the sample center. The time difference between impact time at the sample center measured by the pins and the shock arrival signal recorded by VISAR yields a transit time and velocity through the crystal. It is important to account for the difference in signal travel times to the digitizing oscilloscopes for the two types of signals.

The measurement system used was a dual, push-pull, VISAR system.(6) The dual VISAR with different fringe constants removes ambiguity in determining the particle-velocity jump at the shock when extra fringes must be added. The light was transported from the laser to the target and thence to the interferometer table with fiber optics.

EXPERIMENTAL RESULTS

Initial experiments were performed on samples 1.23 to 4.66 mm thick with input stresses into the crystal of about 1.4 GPa. The wave profiles obtained are shown in Figs. 2 and 3. There is an elastic shock followed by a plastic wave. Decay of the elastic shock strength with propagation distance as well as stress relaxation behind the shock are evident. The elastic shock strengths are similar for the two orientations, but the stress relaxation shows some difference with orientation. The PMMA window has a 12 ns viscoelastic relaxation time. This may distort the stress relaxation for the thinnest samples.

In addition, experiments were undertaken with about 2.4-GPa input stress into the crystal. These would detect the effect of input stress on the elastic precursor strength and decay. One experiment was performed for each orientation, Figs. 4 and 5. These show that the elastic precursor shock is stronger and has more relaxation at a given propagation distance for 2.4 GPa input stress.

The precursor decay results are summarized in Fig. 6. The points at zero thickness are the estimated elastic stresses at the input faces of the crystal. The graph shows that results are the same for both orientations. The precursor decays by about a factor of 4 in 3 mm from 1.9 GPa elastic input stress and a factor of 6 from 3.0 GPa. The decayed stresses are about 30% higher for the higher input stress. Most of the decay is in the first millimeter or so. The input elastic stress was not measured, so it remains hypothetical. For a crystal of this low symmetry the elastic wave may decompose into quasilongitudinal and quasitransverse waves. This has not been dealt with here. The VISAR experiment measures the longitudinal motion.

Shockwave Tabular Results

Table I lists the experimental conditions and measured quantities. If HMX is nonlinearly elastic, the shock slows down as the wave decays. This was the case in explosive crystals of pentaerythritol tetranitrate (PETN).(7) This appears to be so for HMX in that the measured shock velocity is higher for the thinnest samples, Shots 1180 and 1181. The shock velocity computed from the measured transit time and sample thickness is some mean value of the wave velocity over the propagation distance. The final velocity at the interface where the wave profile is measured will be less than this mean value. Halleck and Wackerle estimated the error to be about 3.5% for PETN 5 mm thick.(1) The elastic particle velocity and longitudinal stress in HMX are computed from the intersection of the Rayleigh line given by the initial density times the mean elastic shock velocity and its reflection through the HMX/PMMA interface state in the stress vs particle velocity plane. The

TABLE 1. Results of VISAR Tests for Two Orientations of HMX Crystal[a]

Shot num.	Sample type[b]	Thick- ness (mm)	Impactor u_I (mm/μs)	Interface u (mm/μs)	Elastic precursor U_S (mm/μs)	Elastic precursor u_p (mm/μs)	Elastic precursor P_x (MPa)	Plastic wave U_S (mm/μs)	Plastic wave Rise Time (ns)
1180	110	1.23	0.3185	0.123	4.86	0.085	790	3.48	91
1067	110	3.21	0.3170	0.080	4.16	0.058	460	3.28	122
1166	110	3.18	0.3068	0.083	4.27	0.059	480	3.19	133
1182	110	3.57	0.5209	0.094	4.07	0.068	530	3.39	74
1181	011	1.39	0.3160	0.121	4.51	0.086	740	3.26	79
1068	011	3.00	0.3140	0.086	4.07	0.062	480	3.21	123
1168	011	4.66	0.3132	0.072	4.08	0.052	400	3.26	179
1183	011	3.11	0.5204	0.109	4.31	0.078	640	3.65	47

[a] At 1.4 GPa and u_I near 0.315 mm/μs, the anvils were x-cut quartz and for the 2.44 GPa near 0.52 mm/μs they were Kel-F. The window material was polymethylmethacrylate (PMMA). Shots 1067 through 1168 used two PZT pins to measure the time of impact. Shots 1180 and 1181 used 4 pins.
[b]This is the crystallographic plane in space group $P2_1/n$ that was parallel to the impact plane.

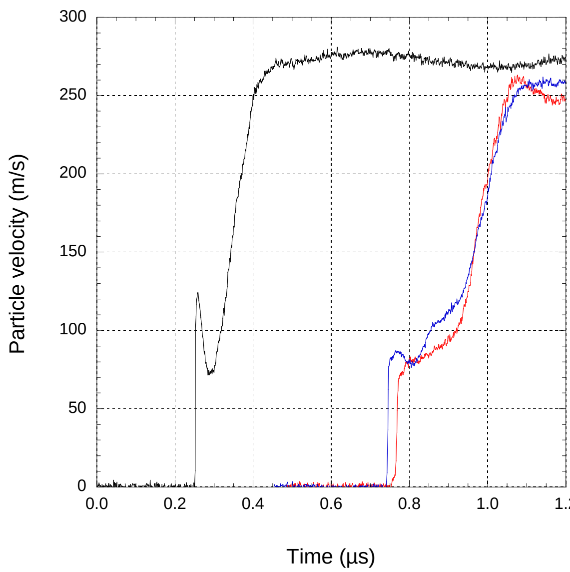

FIGURE 2. Elastic precursor decay for 1.4-GPa shocks parallel to a {110} plane. The profiles are those measured at the HMX/PMMA interface. The black, red, and blue profiles are for samples 1.23, 3.21, and 3.18 mm thick, respectively.

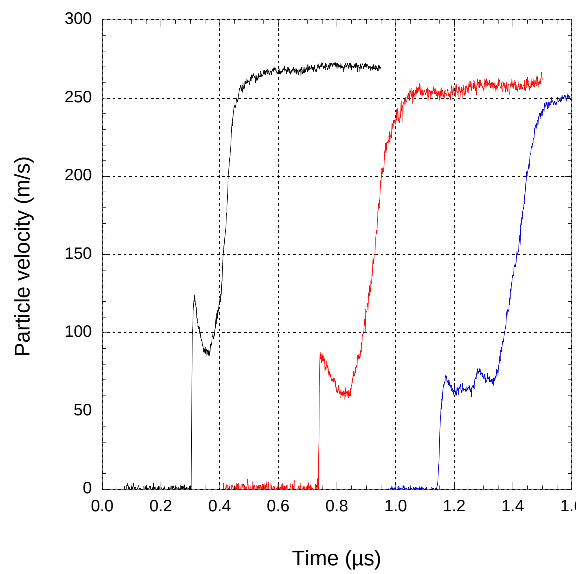

FIGURE 3. Elastic precursor decay for 1.4-GPa shocks parallel to a {011} plane. The profiles are those measured at the HMX/PMMA interface. The black, red, and blue profiles are for samples 1.39, 3.00, and 4.66 mm thick, respectively.

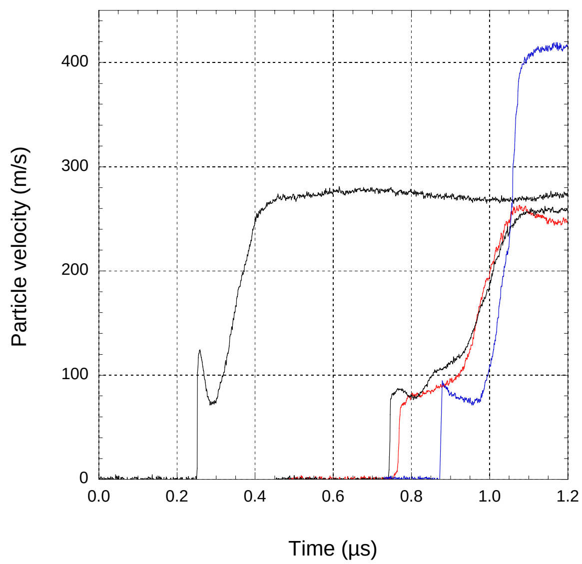

FIGURE 4. Elastic precursor decay for shocks parallel to a {110} plane at 1.4 and 2.4 GPa. The profiles are those measured at the HMX/PMMA interface. The blue profile is at 2.4 GPa, 3.57 mm thickness.

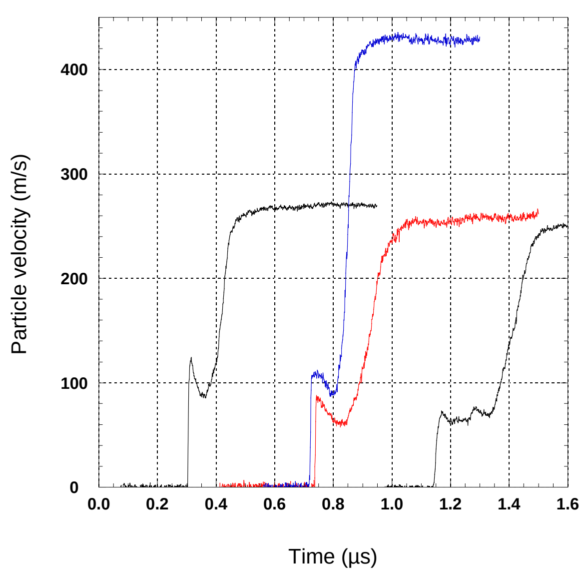

FIGURE 5. Elastic precursor decay for shocks parallel to a {011} plane at 1.4 and 2.4 GPa. The profiles are those measured at the HMX/PMMA interface. The blue profile is at 2.4 GPa, 3.11 mm thickness.

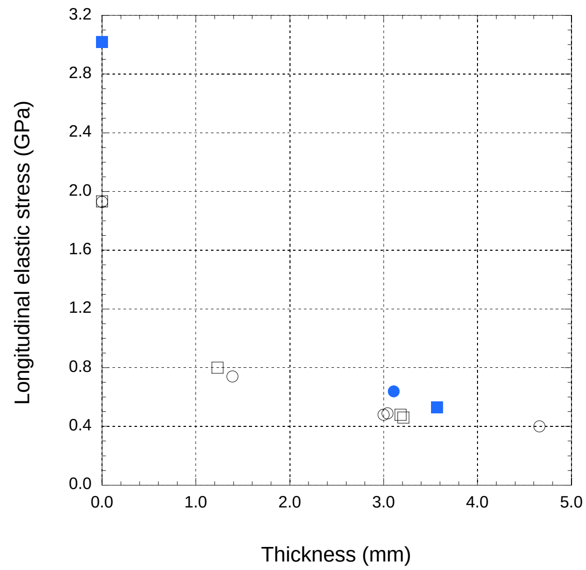

FIGURE 6. Longitudinal stress in HMX vs Lagrangian position for elastic precursor shocks in HMX parallel to {110} and {011} planes. The squares are for {110} and the circles for {011} cases. The solid symbols are for 2.4 GPa final stresses.

plastic wave speed is the Lagrangian wave velocity. The plastic wave rise time appears to increase with propagation distance.

ACKNOWLEDGMENTS

Helpful conversations with Mike Winey and Professor Y. M. Gupta on the behavior of PMMA are gratefully acknowledged.

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